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GUIDELINES FOR COST ESTIMATION BY ANALOGY

Clifton T. Trigg

Army Electronics Command
Fort Monmouth, New Jersey

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It is the intent of this report to provide a critique of a poor estimate, identify the basic problem areas, and provide suggested procedures to minimize the weaknesses of analogy estimating. Detailed step-by-step procedures are introduced and use of some basic statistical measures are presented. The report concludes with a "checklist" of questions the estimator should ask himself to determine the adequacy of his estimating endeavor.

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COST ESTIMATION BY ANALOGY

I. Introduction. Too often cost estimates based on a comparison with some other item are made when a quick estimate is required and there are insufficient or no historical data available for a detailed estimate. The major drawback to this estimating by analogy is that is is essentially a judgment process that requires considerable experience and expertise. Thus, an acceptable analogy can not be hastily made and, in fact, should probably require more effort than other methods such as the use of factors or estimating relationships. There are many pitfalls that must be avoided in order for the analogy method to be successful and useful. In the past, "engineering judgment" has been cited as the rationale for this type estimate. While this rationale is valid, it is too often "top-of-the-head," based on a sample of 1, not documented, and nonreproducible, resulting in an estimate that cannot be evaluated by the user. Actually, "engineering judgment" should be representative of a well ordered scientific reasoning process that can be adequately defined and described in detail.

It is the purpose of this document to review the common or present methods that appear prevalent in analogy estimates, expose their shortcomings, and establish procedural goals to consider in future cost estimating by analogy.

II. Definition of an Analogy. Analogy is commonly defined as an agreement, likeness, or correspondence between relations of things to one another; a partial similarity in particular circumstances on which a comparison may be based. The comparison process is to take note of the differences and similarities of the items being compared. In cost estimating, the analogy can be based on the likeness or correspondence of technical, physical, and/or functional attributes. Noting these similarities to items of known cost, a basic estimate can be made and then adjusted to provide for the cost effects of the differences between the items.

III. Customary Analogy Estimating.

A. Procedures. One of the methods of estimating by analogy which may appear quite often is a comparison of the item to be developed to an item it is replacing. This situation can be seen to present itself frequently since as basic hardware technology advances, replacement equipment is developed to expand performance, to reduce size and weight, or to provide for less expensive life cycle operation. Many such instances are of a product improvement or re-engineering type effort. In any event, such development efforts reflect the incremental advances in technology for a given functional type item, e.g., surveillance, manpack communication, etc. Approaches to estimating the costs per unit hardware these incremental advances incur, leads to a common procedure that is illustrated in the following hypothetical example:

Problem: Estimate the unit cost of item B, a new item for which no specific historical data are available, nor are directly applicable Cost Estimating Relationships (CER) present.

Given: An item A is similar to item B in terms of function and technical characteristics except that new technology will allow for replacement of, say, subassemblies G and H by X and Y. The unit cost of item A is currently $1000.

Procedure: Development personnel "estimate" that subassembly G accounts for 10% ($100) of the unit price and H accounts for 15% ($150). Without these subassemblies, item A would therefore cost $750. Now the engineer's cost estimate is that both X and Y will cost 50% more than G and H or a total of $375. This added to the cost of the similarities of A and B ($750) yields a final unit cost estimate for item B of $1125.

Although the above example might appear oversimplified, the basic approaches and steps are readily evident, and the reader should be able to see how such an approach is used in greater complexity. Also, one should be able to see the use of analogy on a wider basis and thus see the possible application to estimating development time, effort, and cost. However, it should be made clear that the above example depicts the procedure for a poor estimate by analogy, that there exist many hidden assumptions, and the rationale of the estimate is far from sufficient for practical use.

B. Hidden Assumptions. In reviewing the above example carefully, the following assumptions can be noted even though they are not specified:

1. Only one analogous equipment is available.
2. Subassemblies are easily defined.
3. Changes in subassemblies do not present any required modification in the remainder of the item.
4. The apportionment of cost to subassembly level is known.
5. Material, labor, and process differences are known to the extent that the 50% cost increase can be estimated.
6. The cost-quantity relationship and point of comparison is the same for each item.
7. The unit prices are representive of equivalent time periods.

These "hidden assumptions" of course may or may not be true, but the fact that they can be listed, strongly points out the fact that the example was very deficient in back-up rationale for the estimate.

C. Lack of Adequate Rationale. Note that no real rationale is expressed in the above example and many questions are left unanswered, some of which follow. There is no explanation why item A was selected for the analogy, nor why only item A was selected. Could the data base have been enlarged by considering other existing "items" besides item A? Even though a larger data base of additional items might not be adequate to

derive a CER, they might be used for analogy purposes. Drawing the analogy from more than one item will strengthen the confidence of the final estimate.

Also, when considering other analogous items, the need that they be of the same functional family does not necessarily hold. Basically, certain subassemblies or functional portions of the new item are the areas where the analogy estimating is most critical. Do such subassemblies exist in other items of different functional families, and if so were these considered? This would help substantiate the rationale for the cost apportionment estimate for the subassemblies. In the example, no rationale was given. For an estimator to say a portion of an item accounts for 10 or 15 percent of the total cost requires an explanation of how such a proportion was arrived at. If the estimate was "expert judgment" it should be stated as such and a written rationale backing up the judgment should be present. If the estimate was derived from spare parts procurements (spare part cost vs total item cost) was any check made on the remaining "parts" costs? The total unit cost of item A should also be explained in terms of prototype cost, production cost and the year that the cost had occurred. Also, how many of the items were procured? Has the price about stabilized? Is it a competitive price or sole source? Is the quantity used comparable to the quantity of the new item being procured? If not, what procedures or logic were used for the estimate? The answers to these questions are necessary to, in part, also substantiate the "50 percent" cost increase for the new subassemblies over the existing ones. Other rationale is further required to back up the "50 percent", such as consideration of material costs, labor costs, and maturity of manufacturing process and market.

A final area to consider in the rationale is the addressing of possible interaction between the newly incorporated features and the "similar" portions. Are there any engineering problems created by the substitution of subassemblies? Will the remaining areas remain the same in function, but possibly not in layout or configuration? If the similar portions are altered, the production cost history may well have to be looked at carefully to account for the establishing of a new line and the provision for being on a different part of the learning curve.

Without a written statement addressing the above points of backup rationale, the user or recipient of the estimate would have difficulty accepting the estimate with any degree of confidence. Also, even the estimator at a later date would have difficulty reproducing the estimate although knowing what the final figure was he could probably back into it again with some rationale, probably not the same as the first time. There is a need then, to emphasize the requirement for rationale and especially the documentation of that rationale. Estimating by analogy should not be considered an easy method and should not be used in a slip-shod manner or presented as a cursory endeavor. The next section will expand further on the possibilities and especially the problems of using the analogy method for cost estimating.

IV. Problems Inherent in Analogy Estimating.

A. Relationships to Other Methods. In either an implicit or explicit manner, all cost estimates can be considered to derive from an analogy base. The statistically derived cost estimating relationship (CER) implies that the data points used are related by some analogous set of parameters, performance or physical characteristics, and for this reason the CER user is always cautioned in the extension and use of the CER. In the CER, the statistical measures of "goodness of fit" and explained variations imply the strengths of the analogy. Much has been written about the warnings against using an "old" CER to project or estimate the cost of items outside the limits of the CER. Usually this encompasses extreme extension of the parameters and/or a major difference in technology. These points will be treated later since they are basically drawing an analogy on a previous analogy, and therefore the underlying assumptions will have to be investigated.

Explicit cost estimating by analogy occurs when the estimator uses one or more similar items as a basis for developing the cost estimate for a new item. This is the most customary use of the analogy and is usually without statistical backing although the possibility of using statistical methods might be applicable.

Even the estimate made by "expert" judgment is, in a way, the use of analogies. The expert draws on past experience and logical reasoning to develop his estimate. Although specific data points may not be capable of being recorded, the general points considered and treated by the expert can be put down on paper for the record. In fact, the exercise of writing such a rationale could well provide the expert with the desire to give the estimate more critical thought.

B. Uncertainty (Technical, Schedule, Economic). When developing a Life Cycle Cost Estimate (LCCE) by analogy, the three basic areas of R&D, Investment and Operating must be addressed. The estimator usually concentrates first in the "unit price" or that price to be paid when the item is in production. The second area is usually the engineering effort required to design, develop, and bring the item to the point of production. The final area is that of the costs of operating and maintaining the item after it has been procured.

It is the interaction of these three areas plus possibly undue optimism or project enthusiasm that so often leads the way to poor cost forecasts and estimates.

In reviewing the first area, unit price, one may consider that a priori knowledge exists in the form of technical characteristics, weight, size, and cost constraints. However, unknowns exist in the form of possible technological change effects, economic change effects, and schedule change effects. These three effects cause further complication through their interaction.

Contemplated changes in technology refer to a certain degree of risk or uncertainty. This uncertainty is then further affected by economic uncertainty which might be specific to the technology or more general in nature. Technological risk further implies uncertainty as to forecasting schedules, thus further involving economic change effects for different time frames.

For example, if an estimator is dealing with the problem of estimating a new radio set, it is reasonable to believe that the technical characteristics for the most part will be similar to past radio sets. However, the incorporation of new technology may be the main purpose, say to achieve smaller size, lesser weight, higher reliability, or other such goals. This places one in the position that the analogy must be drawn with respect to technological change, not to the technical or performance characteristics of past systems. To accomplish this requires detailed thought, for the premise that such a development is planned implies that some conclusion has been reached, even if subjective, of the economic efficacy of the proposal.

One should, however, try to keep this assumption out of mind and concentrate on the details of analogy. When dealing with the areas of technical, economic, and schedule uncertainty in terms of the analogy, the effort should be concentrated on the difference of design, of effort required to redesign, of parts, module and labor costs, etc., at present prices and market, similar costs at forecast prices and market, and rationale for the difference in prices. Component development is of an almost continuing nature, thereby in effect changing the overall state of electronic technology. Early use of the new components in equipment development can be considered the very momentum of equipment change. However, early use of such newly developed components and parts finds their prices high because of the lack of sufficient market size and production capabilities. This could lead to either estimates that are too high or estimates that are too low depending upon the assumptions used in forecasting the future market environment. Such questions as, "will there be a commercial as well as military market for the new compoents?" should be considered. Will the environmental and stress requirements unduly separate the two market segments? What patent conditions prevail and what similar components are being marketed? What about market timing? Can it be expected that lowest cost will occur when it is planned to produce and procure the new equipment or will the market stabilize sometime after first procurement of the equipment?

The thought comes immediately to mind that the engineer or developer has enough problems in the technical area and cannot (and probably should not) expend the time and effort necessary for "market research." However, in his estimate he implies market knowledge. An alternative that might be considered is to select some person or persons and task them with a general responsibility for maintaining at least gross cost trends in the component field, much like technological trends noted by technological forecasters. In this way, where the present part price is known by the engineer, the "market monitor" might be able to project more quantitatively the "production" price for a given time frame.

People like to believe that items, the cost of which they must estimate, are completely new and unique. This is especially prevalent in military programs since the commercial world doesn't have missiles, tanks, and complex weapon systems. However, upon reflection is should be noted that although the end use and configuration of an item might not have a commercial counterpart, the technology, materials, manufacturing processes, and even components do exist in the civilian sector. Scientific and technological state-of-the-art is not unique to a given investigator, but usually permeates the entire scientific community. This is readily apparent when a breakthrough, discovery, invention, or development is announced by an individual investigator. In very little time, publications are filled with the findings of other investigators who were pursuing parallel efforts.

The gap in time between discovery and the development of the discovery for useful application is, in reality, the greatest obstacle that besets the estimator and sets the commercial and military sectors aparts. The commercial world enjoys the advantages of that yardstick called the "market" where prices are set in terms of supply and demand. Competitive forces tend to restrain the introduction of the "new" until the price and market size appear adequate to yield a profit.

The estimator of costs for military items does not find himself in this same supply and demand market. Instead, he must evaluate for acceptable "prices" in a strategic and tactical competitive "threat" market place, where the actual competitive pressure is to maintain a superior defense posture in an uncertain environment. When the opportunity to develop a superior item presents itself, the estimator must estimate the development time and cost, the production time and cost, and the impact on field costs. Time is a transcending variable here and its economic effects should be apparent. Failures or delays during development will result in stretch-out coupled with increased costs. Inflationary effects will be making their mark throughout the program. Component and material markets as well as manufacturing processes might mature significantly with time, lowering ultimate item costs. Early goals of MTBFs and logistic concepts may not be achieved in the field and these costs may be increased. All these are possible areas of concern when dealing with uncertainty and it must be dealt with early on the first estimate when the fielding target date is six years or so downstream. Analogies can be helpful in evaluating uncertainty, but again care must be taken in defining the assumptions and furnishing the rationale.

V. Procedures to Consider. The first step to be undertaken in cost estimating is basic to all approaches, including analogy; determine and state comprehensively what is to be estimated. This should include more than naming the item and listing its desired attributes. Specify the likely time requirements and proposed quantities. List the predecessor items if the item is of an evolutionary class. Spell out what makes this item new. Don't limit this to performance - relate it to parts, circuits, materials, processes, etc., wherever possible. Now the analogy process can begin.

Conduct a search for comparable items. In doing this make a concerted effort to go beyond the obvious. Include commercial items when possible. Subdivide the item to be estimated into functional and/or component categories. List these elements in the order of their estimated contribution to overall cost. Those elements that are thought to impact the greatest on the overall cost should be concentrated upon. Search for comparable elements. At the element level, this may lead outside the obvious generic family of the overall item. Parallel the search for comparable elements with a search for CERs. On the first run through don't evaluate too critically the CERs found. If they appear to have some merit, keep them for later evaluation. Remember that the more methods or approaches that can be undertaken to develop the estimate, the stronger the rationale and the confidence will be for that estimate.

Normally, the greatest attention should be applied to those elements of the overall item that are thought to be the most expensive. Be careful here though, because the less costly elements may well, collectively, account for the greatest portion of the item. This can be especially true when deployment and numbers are considered. Oftentimes, a lower cost element when multiplied by the number to be deployed can result in an overall cost greater than the overall cost of a higher cost element which will be deployed in lower numbers. Combinations of lower cost elements can pyramid.

Now, for the major item to be cost estimated and for its elements there should exist a "data base" of sorts. Note that no actual estimating has been recommended up to this point, nor has a real evaluation been made of the "data". Purposely, this has been done to keep from forming a mental set on a figure or figures that might provide motivation for discarding non-confirming data prematurely.

In evaluating the data, the first thing to look at are any CERs that were found. If valid CERs are found, hardware cost estimating by analogy is not necessary. However, CERs are sometimes misapplied; therefore, the user is cautioned to "know" the CER before relying on it for the estimate. It is difficult to delineate all the pitfalls that can be encountered with a CER, but some of the more obvious evaluation criteria can be listed. For example, the age of the CER could make its use questionable. The age should be analyzed carefully, and this can only be done effectively if the supporting data base is known. A review of the data base should include a determination of differences in technology as well as price level changes. Thought should be given to possible adjustment of the CER if the relationship is still logical and a rationale for the adjustment is evident. Even if the CER cannot be adequately adjusted, keep it for the time being and later it might be used in the analogy approach.

Continuing further on the subject of CERs, it is now time to look at the analogous items and elements of the data base and attempt to develop CERs from them. Document the findings.

Now it can be assumed that the CER approach is ended and what is left is to develop the necessary analogies.

The major item analogy should be taken on first. Start by listing the similarities and differences with the analogous items. Establish a comparable market price situation for the analogous items. That is, make the necessary adjustments for quantity comparability and for the economic effects of time. In this regard, make use of historical improvement curve trends, when possible, and the necessary Inflation/Escalation Guidance established by the command. On commercial items used in the analogy, quantity/price relationships may not be available. If such data are not available, make a statement to that effect to assure that comparability adjustment is not assumed.

A table of data should now exist in a form somewhat like the following:

Element/Function	New Items	Analogous Items					
		1	2	.	.	.	m
A							
B							
.							
.							
.							
X							
Basic Cost	\$X	$\$Y_1$	$\$Y_2$	.	.	.	$\$Y_m$
Adjusted Cost	--	$\$Z_1$	$\$Z_2$	.	.	.	$\$Z_m$

The cells of the table compare the similarities/differences of the various items in whatever terms these elements are normally expressed in. This table should result in highlighting the areas of major dissimilarities on which further estimating effort will have to be concentrated. The importance of the search for analogous sub-items or elements should now become apparent, for this is where the estimating procedure has arrived. It should be possible to conduct a more critical and quantitative approach to the estimate now instead of the "judgment" approach previously critiqued. Judgment must still be present, however, in making the choices of what data to use and how to use it. Again, it is highly recommended that such decisions be documented.

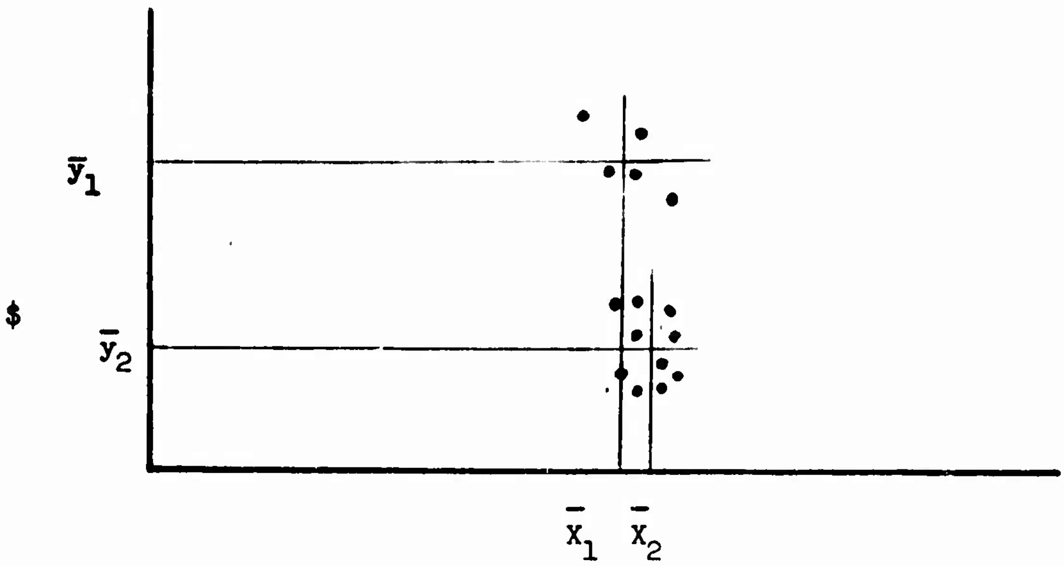
The attempt here is to modify Yi in some logical manner to arrive at $X. If only one analogous item (Y_1) were used, the result would tend to be a point estimate for $X. The use of more than one item should, however, lead to a range of $X's, thus providing a better display of uncertainty. Also, it should provide the impetus for an iterative procedure of returning to modifiers for further review. The modifiers may take on the form

$$\$X = kY + j$$

Where k represents the effect of differences in similar elements and j represents additional elements not found in Y. The modifier "j" can also be seen to take on a negative sign when Y contains elements that do not exist in X. This appears to be a restatement of the original analogy that was critiqued, but it should be noted that contributing percentages are not used in this approach. Attention is being placed on the "differences" and adjustment will be made to the "total" cost. Gross cost estimates of these differences based on complexity, technology, and weight may well be better than detailed analysis of performance and functions. For example, the cost to produce elements consisting of discretee components should be more a function of complexity and weight than of whether the element is a preamplifier or a modem. To the people in the manufacturing environment, their view is one of fabricating and/or assembling chassis' or boards containing so many active and passive elements. Their concern is not what the item does eventually. Saying this should not be taken to belittle the complexity and expertise of any commodity area. That expertise manifests itself in the development, design, layout, and packaging of an item, but not necessarily in production. Thought would have to be given here to any special deviations from normal production processes or to any unique components.

In specifically expressing the use of gross estimating, an attempt is being made to narrow down the judgment process, and to stay above the piece part pricing techniques. Even where piece part data are available to some extent and the parts are highly repetitive in the design, care must be taken. Multiplying small cost figures (e.g., ¢ per weight) be large numbers can result in greater errors than gross estimating by complexity analogy.

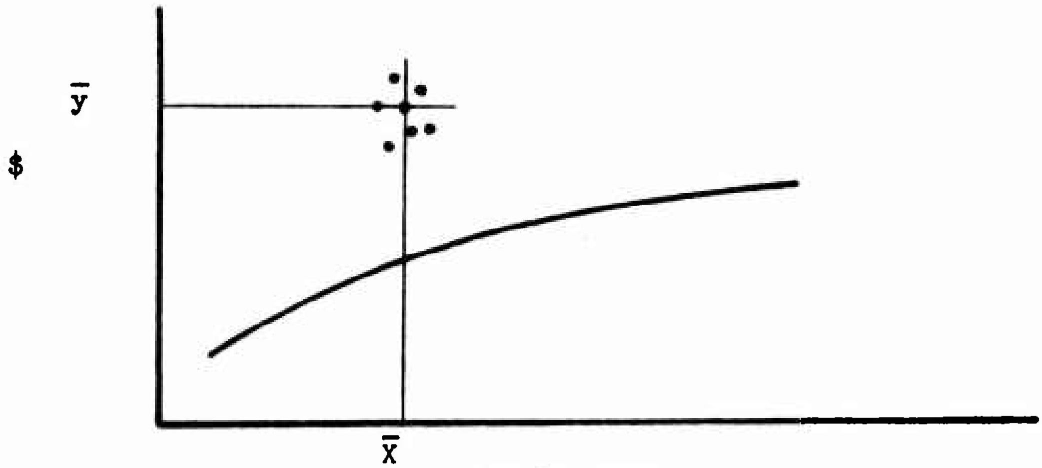
If the area of difference to be estimated happens to be some discrete defineable subassembly, comparison to other military and commercial items may be more evident. A commercially based CER might also be used to advantage. If analyzing other military and commercial items makes CER derivation appear impossible, one approach would be to plot the scatter diagram of the data available. If it is possible to group the data similar to that shown in figure 1, the arithmetic means of the data for both y and x axes may be obtained and the significance between the means can be tested by the student's t test. It is evident that in most cases the significance of differences in the y mean values will present no great difficulty to ascertain. Much more effort should be placed on assuring the insignificant difference of the x mean values. This should be done on all the major contributing parameters (x values) of the samples. Once this is accomplished the difference in y mean values has some



Performance
Figure 1

meaning. This will provide an "average" military analogous estimate with a range denoting the uncertainty. Also, a check on the propriety of the estimate is obtained by the difference of the means which in essence, is a "militarization" factor, which should be amenable to explanation. If this factor appears logical and can be supported with rationale, e.g., low productive yield on parts meeting environmental needs, then it can also be used to some advantage for application to commercial points outside the grouped data.

Another method occurs when a CER can be obtained from commercial items. Often such a CER is possible, but military counterparts tend to group about a narrower portion of the CER parameters. An example of this is shown in Figure 2.



Performance
Figure 2

Again, the method of comparing means can be used and in addition, if the parameter relationship of the CER is deemed to be logical for military items, a parallel CER may be constructed through the means of the military items. Again, the "militarization" factor will have to be evaluated for feasibility.

The above two approaches, as outlined, assume rather strongly that the basic technology and complexity are comparable. However, very similar approaches can be taken to generate factors or functions of technological change. Figure 3 displays what might happen, in general, for changes in technology.

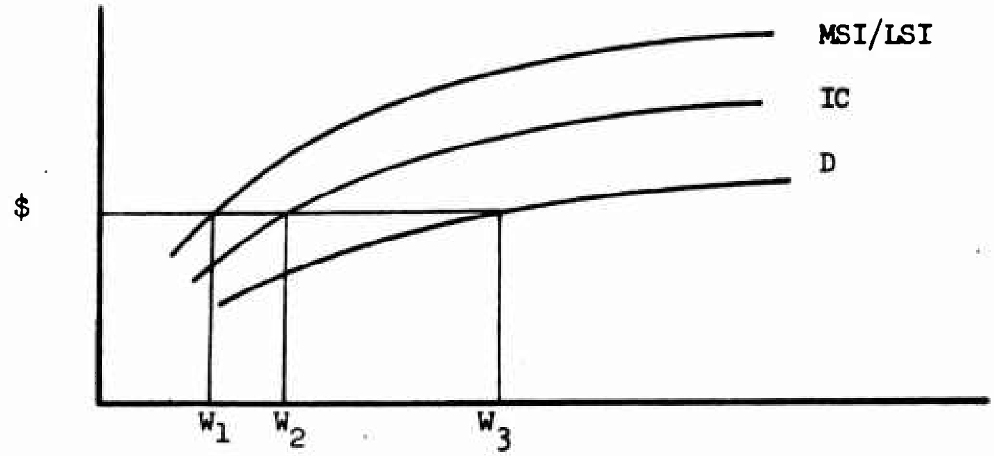


Figure 3

As indicated, for any given weight, the cost might be found to increase depending upon whether one is considering discrete component design (D), integrated circuits (IC), or medium, large scale integration (MSI/LSI). Such a relationship would probably hold when the different technologies are at different periods of maturity. As the newer technologies mature, the cost functions should tend toward the lower bounds.

The higher cost per unit of weight of a new technology should not be viewed as detrimental, however, since as shown in figure 4, performance

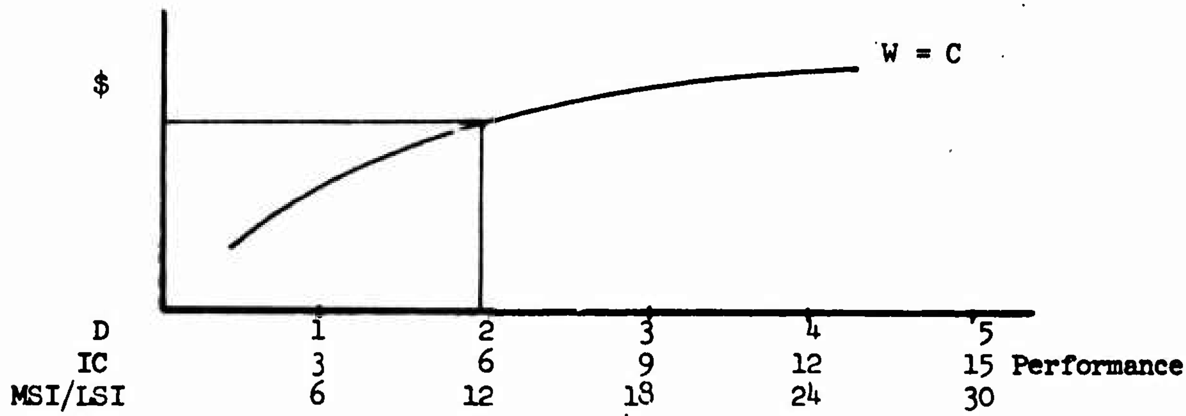


Figure 4

for a given weight will be expected to increase significantly for increases in technology. The same methods of comparing military items to commercial items treated above can be used to generate or estimate the effects of a change in technology. Here, it is assumed that the more mature technology will furnish a substantial enough base to allow for comparison to the fewer known points of the new technologies. Also, as shown in figure 5, for some hypothetical CER ($ vs parameters), a technology function may be derived. In the example shown, the increase in performance is not offset by a decrease in weight in terms of cost, hence an increasing f (Tech).

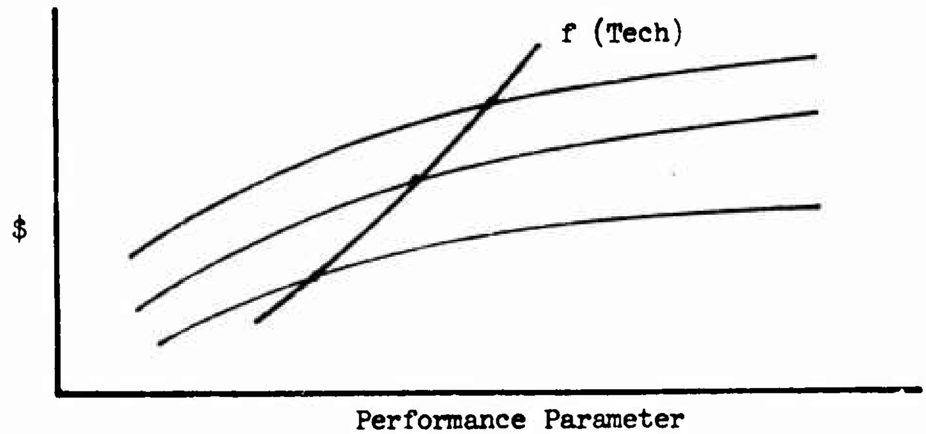


Figure 5

It should be realized by the estimator that f (Tech) could follow the basic CER function, thus moving along the performance axis for increasing technology. This is analogous to figure 4. Also, where the increase in performance exceeds the decrease in weight, the technology function may take on negative slope parameters, thus indicating new data points below the basic CER.

The above treatise does not imply that the estimator must derive such functions, but is offerred to aid in the development of rationale. If a single point or a few points representing newer technological application are available, their position relative to an older, mature technology will provide the basis for estimating higher or lower by use of analogy.

Using one or more of the above approaches in estimating the "differences" in analogous items should now allow for adjustment of the basic item price to yield an estimate for the new item. This should suffice for developing the cost estimate of the item and now permit the treatment of developments costs and operating costs by analogy. These areas are more tenuous and require greater care in the identification and treatment of assumptions. Whereas the estimation of a "unit price" relied heavily on historical evidence, more care should be used in evaluating past efforts in development or operating costs. Manufacturing is faced with quantity output to a demand/price environment.

Item performance is a measureable entity and in order to compete, a manufacturer must consider labor/capital trade-offs to remain competitive in price for given performance. Development, however, is faced with the judgment or evaluation of the best technical approach proferred and the validity of the price or value is not easily determinable. Relying rigidly upon historical development times and cost of analogous programs can be seriously misleading in several ways. Two axioms are normally present and when viewed critically lend some insight for estimating. One is that "history repeats itself" and the other is that "time is money". The repetition of history is the most common base for the analogy approach of making the estimate. However, it should be considered that estimates become goals, goals bring on controls, and controls are usually broken, resulting in excess cost. So, if the estimate is based on history, it is likely to fall in a region somewhat lower than the cost finally realized. In essence, the estimates tend to predetermine the outcome and prolong the historical chain, thus giving a basis for "rule-of-thumb". Such a chain will continue to reinforce the rule-of-thumb.

The development effort should be analysed carefully. In analogy this must be done against a historical base. It can, however, be done on a segmented basis, such as the effort to derive the design plan, the amount and type of testing required, the building of prototypes, etc. The time and effort analogy should be based on the scope of a program, e.g., a completely new design of new materials, a new design of present technology, a redesign of equipment, an upgrading, etc. Consideration should be given to the "state-of-knowledge" present at the time of the estimate - how far has prior development been carried, e.g., through AD models, etc? Also, remember that time is money and development procurements can be likened to an employment game, since a defense contractor's major assets are his knowledge and skills formation (people). It is not unheard of for defense oriented employers to realize a return on capital investment extremely higher than the actual realized profit. The name of the game for a contractor is employment, and his goals are profitable continuity and expansion. The Government's goals are adequate item performance, minimization of costs, and shortening of development time. The goals of the two parties conflict as in any game and it might be said that the Government can lose more than the contractor can gain. For the purpose of this paper, the main point is that the strategy must be to counteract the potential contractor's goals to a point satisfying both parties. To accomplish this, the estimator and manager should consider whether or not analogous programs could have been accomplished in shorter time and if actors that caused time delays previously can be overcome. These are points that should be addressed specifically in the analogy and fully documented.

Operating costs present the most difficult portion of all costs either to estimate or to determine. Because there is a paucity of data representing actual field use, it is difficult to structure a meaningful analogy on an actual use basis. For this reason, most operating costs are estimated

deterministically on the basis of estimated or factory tested MTBF and MTTR along with various factors covering the several cost elements of the operating phase. Basically, this methodology is not incorrect, but one might normally expect that it underestimates the costs because it assumes that non-field data is fully representative of field data. Sensitivity analysis is usually introduced to demonstrate the effects of the uncertainty, but does not help in determining the most likely costs. Analogy may be helpful here, if some field data are available. It has been said that MTBF decreases as the distance from the manufacturer increases. How true this is must be considered, for not only would it affect the cost estimates but it would affect the operating philosphy as well. In an attempt to account for these changes, PEMA secondary item requisition for non-common parts of analogous equipments might provide an idea of whether or not consumption was greater or less than expected. Also, on analogous items, reports of field problems should be ferretted out where possible. The new concept of Operational Testing by "users" and the use of elapsed time indicators should provide better relationships in the future for plant vs field test results.

Each cost factor or computational algorithm should be scrutinized carefully in terms of basic assumptions and possible magnitude of error generation. All operating costs should be looked at in terms of constant dollars and inflated dollars and consideration should be given to program slippage.

VI. CONCLUDING REMARKS. Cost estimation by analogy is probably one of the most powerful techniques for estimating if a dedicated effort is pursued. However, history has shown it to be severely lacking in credibility because it is too easy to do a slip-shod job to meet "rush" requirements. If analogy is to gain the proper respect due it, its future use must reflect comprehensive, well documented efforts backed by very strong rationale. The development of Cost Estimating Relationships (CER) has become the major thrust of many, but when viewed in their proper perspective, CERs are also analogies. Very seldom is it possible to find or develop CERs for all that needs to be estimated. Also, CERs can be hazardous in blind application even if they are accompanied by good "statistics". In the final analysis, analogy transcends all "parametric" estimating and finds use in all phases of the development-production-operation cycle. The foregoing section of this paper has delineated many approaches that can be taken in estimating by analogy. The treatment is not exhaustive, but hopefully is motivating in nature toward better use of analogy.

The following is a summary check list of questions the estimator might ask himself to determine how comprehensively he has conducted his effort of estimating by analogy.

Check List:

For Item Cost, Have I:

1. Comprehensively defined the item to be estimated?
2. Broken the item down by: function?
components?
3. Ranked the relative breakouts by estimated cost importance?
4. Conducted a thorough search for: comparable military items?
comparable commercial items?
comparable contributing elements?
5. Conducted a thorough search for CERs?
6. Assured that the "data base" established from the search contains all pertinent information such as: dates?
quantities?
characteristics?
technology types?
problems?
7. Identified and documented the data sources?
8. Evaluated the data and completely documented the evaluation?
9. Adjusted or normalized the data for use?
10. Documented the adjustments and their reasons?
11. Set up a table of data (element/function vs items)?
12. Isolated the "differences" between the item to be estimated and the analogous items?
13. Used CERs to the extent possible?
14. Used as many analogous approaches as practicable?
15. Adjusted the "total" item cost to account for effects of the "differences"?
16. Documented the entire effort?

For Development Costs, Have I:

1. Defined the type effort (new, redesign, etc.)?
2. Conducted a search of similar past efforts?
3. Conducted a search of similar sub-efforts?
design plan?
testing?
etc?
4. Reviewed problems encountered on past efforts?
5. Documented and validated any "rules-of-thumb"?
6. Drawn as many time and effort analogies as practicable?
7. Documented the entire effort?

For Operating Costs, Have I:

1. Made a deterministic estimate based on reliability projections?
2. Conducted sensitivity analysis on the key variables?
3. Checked analogous equipments to determine what "actual" vs "projected" reliability was?
4. Checked for extraordinary PEMA secondary item requisitions on analogous items?
5. Ferreted out any reports of field problems on analogous items?
6. Incorporated the findings of 4 and 5 above in the substantiating of the sensitivity analysis (2)?
7. Documented the entire effort?